Rood (Ogden N.)

Pt. 2nd.

Rood (O. N.)

N. Haven,

[FROM THE AMERICAN JOURNAL OF SCIENCE AND ARTS, VOL. II, SEPT., 1871,] 3. S.,

ON

THE AMOUNT OF TIME NECESSARY FOR VISION.

BY OGDEN N. ROOD,

PROFESSOR OF PHYSICS IN COLUMBIA COLLEGE.

IN the celebrated experiment of Wheatstone on the duration of the discharge of a Leyden jar, the conclusion was drawn that distinct vision is possible in less than one millionth of a second. The incorrectness of the data on which this conclusion rested was afterward pointed out in an admirable investigation by Feddersen, who remarks on this point: "One cannot hereafter assume, in optical and physiological experiments, that the discharge of a Leyden jar is an instantaneous act; but at the same time, by the determination of the greatest suitable resistance, it will be possible to limit the discharge to its least possible duration."* The smallest measured duration obtained by Feddersen was one-millionth of a second.

In an article in the present number of this Journal I show how, by the use of a much smaller electrical surface, I obtained and measured sparks the duration of whose main constituent was only forty billionths of a second. With their light, distinct vision is possible; thus, for example, the letters on a printed page are plainly to be seen; also, if a polariscope be used, the cross and rings around the axes of crystals can be observed with all their peculiarities, and errors in the azimuth of the analyzing prism noticed. There seems also to be evidence that this minute interval of time is sufficient for the production of various subjective optical phenomena: for example, for the recognition of Loewe's rings (using cobalt glass); also the radiating structure of the crystalline lens can be detected when the light is suitably presented to the eye.

Hence it is plain that forty billionths of a second is quite sufficient for the production on the retina of a strong and distinct impression; and as the obliteration of the micrometric lines in the experiment referred to, could only take place from the circumstance that the retina retains and combines a whole series of impressions, whose *joint duration* is forty billionths of a second, it follows that a much smaller interval of time will suffice for vision. If we limit the number of views of the lines

* Pogg. Annalen, Band cxiii, p. 453.

presented to the eye in a single case to ten, it would result that four billionths of a second is sufficient for human vision, though the probability is that a far shorter time would answer as well, or nearly as well. All of which is not so wonderful, if we accept the doctrines of the Undulatory Theory of light; for according to it, in four billionths of a second, nearly two and a half millions of the mean undulations of light reach and act on the eye.

New York, June 30th, 1871.

On the nature and duration of the discharge of a Leyden Jar connected with an Induction Coil.

BY OGDEN N. ROOD,

PROFESSOR OF PHYSICS IN COLUMBIA COLLEGE.

PART SECOND.

IN the first part of this paper* I described certain results obtained with a Leyden jar of moderate size connected with an induction coil; measurements of the total duration of its discharge were given, and it was shown that the luminous effects were mainly concentrated in the *first act*, which was found so short as to be quite immeasurable with the means then at my disposal. As one main object in these experiments was the production of an illumination as nearly instantaneous as possible—the intention being to employ it hereafter in a totally different investigation—it occurred to me that the desired end might be still more perfectly attained by the use of a quite small electrical surface. In the set of experiments above mentioned, the coating of the jar was 114·4 square inches, so this was now replaced by a jar with a coating of only eleven square inches. The sparks it furnished, when connected with the same induction coil, were perfectly satisfactory as regards illuminating power; and I at once proceeded to measure their duration, employing the means and apparatus already described. For the mirror I used silvered glass, the polished *silver* side reflecting the light; its size was half an inch square. The rod figured at W was removed, with of course great advantage to the ve-

* See this Journal, vol. xlviii, Sept. 1869.

1871, 2.-3., II, 160

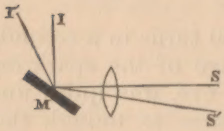
locity; and as several discharges occurred in a second, it was seldom that the weight ran down without at least one good observation being obtained.

With this mirror making not less than 300 turns in a second, I was greatly surprised to find that the image of the spark on the ground glass, as viewed by the naked eye, was quite unaffected in appearance, looking about the same as though the mirror had been stationary. This experiment, which was repeated daily, gave uniformly the same result, and proved that the total duration of the discharge was incomparably shorter than in the case of the larger jar. When the paper with the black lines ruled on it was used, they were seen equally distinct with the highest as well as with the lowest velocities; and all the evidence went to show that the discharge of this small jar consisted of a *single act*, whose duration was immeasurably short. Knowing well the inestimable value in certain physical inquiries of a source of illumination of this character, a series of more deliberate experiments were now instituted for the purpose of examining in detail its nature, and, if possible, duration.

The mirror was made to revolve 300 times in a second, the image received on the ground glass, and viewed with the naked eye, platinum wires $\frac{1}{86}$ of an inch in diameter being used, with a striking distance of five millimeters. The result was as above given, the spark-image being totally unaffected—once only at one of its ends a very small and faint streak was noticed. Replacing the ground glass by plain, and magnifying the image of the spark with an eye-piece, it was now at last certainly ascertained that it was followed by a minute and faint tail or streak situated at its extremities. The illuminating power of this streak was trifling—less than one per cent of that of the unanalyzed body of the spark it belonged to—and its length was hardly much greater than the breadth of the micrometer lines previously employed. The platinum wires were replaced by others of zinc, and, as was expected, the tail was rendered more easily visible, and attempts were made to compare its size with the thickness of single micrometer lines, which proved difficult and uncertain, owing partly to the variable position assumed by the spark-image in the field of the eye-piece. Although for practical purposes the duration of this faint tail or streak is only of slight importance, still for the sake of completeness a new form of micrometer was devised capable of effecting its measurement, and I cannot but hope that the general plan employed may hereafter prove useful in parallel lines of investigation. The point to be gained was to have the micrometer always applied to the object to be measured; the spark-image must carry its own micrometer—must in some way be made as it were to measure itself.

Micrometer.—Let the spark be generated at S, fig. 1; its light, falling on the stationary mirror M, will form a spark-image at I, in the plane of the observing plate. If at the *same* instant a second spark be generated at S′, its image will fall at I′. Let us suppose that during the simultaneous production of the two sparks, the mirror is rotating so rapidly as to be able to draw them partially out into streaks, then we shall have the appearance presented by fig. 2, the distance between I and I′ varying with the original distance between the sparks; and it is evidently possible to diminish this quantity, so that the tail of I should just be in contact with the edge of its companion. In this way, the length of the tail can be measured, it being afterward only necessary to measure on the observing plate the distance of the spark-images apart when seen with the stationary mirror. In actual practice, at S′, I placed a plane mirror, and by varying its inclination with a screw, obtained any desirable separation of the images, without greatly injuring the focal adjustment. A still better arrangement is to remove this mirror, and substitute for it at S′ a small strip of white paper, inclined 45° so as to receive the light of the spark, as its feebler luminosity, straight edge, and the perfection of the joint focus, all tend to increase the accuracy of the results. This paper was supported by an appropriate stand, and was moved till the right distance had been attained.

1.



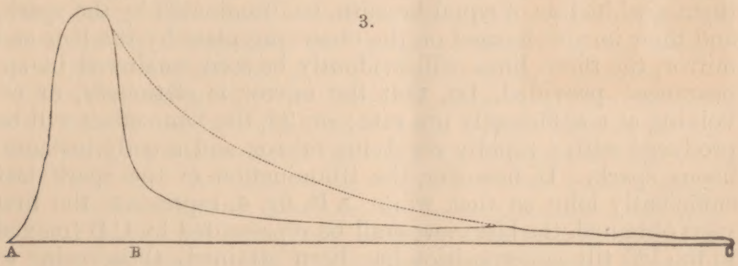
2.

Total duration of the discharge.

As was to be expected, this was found subject to some variation in individual sparks. With zinc points, and a striking distance of one millimeter, the duration varied between ·000001 and ·0000025 of a second, a duration as long as two and a half millionths of a second being somewhat rare. With greater striking distances, or with platinum points, the tail was not so well developed; but sets of more hasty measurements showed that its duration in these cases did not widely differ from the figures above given. With zinc points, and a striking distance of *two* millimeters, a couple of careful experiments gave respectively a duration of ·0000022 and ·0000019 of a second. The room in which the determinations were made was usually not entirely darkened, but kept in something of a twilight condition, which is more favorable for preserving the accommodation of the eye; from time to time these results were compared with those obtained in a dark room, but nothing new of importance was thus elicited.

Although with the improved micrometric method above described an interval of time as small as one millionth, or half a millionth, of a second could, as has been seen, be directly measured, still with its aid I never detected any sign that the *duration of the great body of the spark was other than absolutely instantaneous;* as, however, all the light of the spark is due to incandescent material particles, we must suppose that an infinitesimal portion of time is required for attaining its maximum brightness, and owing to the same reason its disappearance demands another distinct period however excessively minute. Hence, we may represent the luminous effects of the discharge by a

3.



curve conforming more or less to that here figured, in which intensity of light is measured in a vertical, time in a horizontal, direction. This curve then, (the unbroken line), serves to give some idea of the relation existing at successive intervals between the luminosity and duration of a single discharge, and its continuity indicates the fact that there is no real interruption at any moment. The curve is of course adapted for that part of the discharge next to the electrodes, or for electrodes that are near together; for in the case where they are distant five or ten millimeters, the part between B and C is not so well developed.

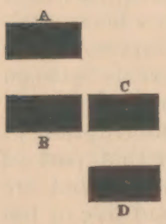
It is this steep peak A B which constitutes what, in the first part of this paper, I have characterized as "the first and most brilliant act of the discharge;" though with a larger Leyden jar (114 square inches), it is neither so steep as in the present case, nor so solitary, being followed by a series of minor elevations, while with a *small jar* the effective luminosity of the discharge is almost wholly concentrated in it. In the present case, then, the far greater brilliancy of the light at the beginning of the discharge practically separates it from what follows, practically constitutes it a first distinct act, and renders its measurement highly desirable. Later, some evidence will be adduced to show that the curve really has a form substantially like that here given, instead of some such one as is indicated by the dotted line.

For the purpose of measuring, or at least setting, a limit at one side of the infinitesimal period of time involved, I employed

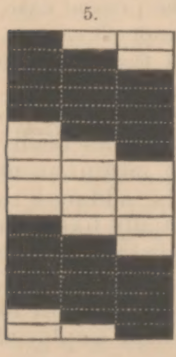
the same general device of black and white lines previously described. But it will now be necessary to make a more *accurate* analysis of their relation to the problem than was given in Part First of the present paper, as I noticed after publication that, owing to an oversight, the statement there printed is partly incorrect, though the results there given are not vastly affected, and may be corrected by reading on the last page, that the discharge was proved to last less than *four*, instead of two, ten-millionths of a second. (Its actual duration I have recently obtained, and state at the end of the present paper.)

If two black lines of a certain breadth, inclosing between them a white line of equal breadth, be illuminated by the spark, and their images formed on the observing plate by the lens and mirror, the three lines will evidently be seen unaltered in appearance; provided, 1st, that the mirror is stationary, or revolving at a sufficiently low rate; or, 2d, the same effect will be produced with a rapidly revolving mirror and a truly instantaneous spark. If, however, the illumination of the spark last sufficiently long so that while A B, fig. 4, represents the first view obtained, the last view shall be represented by C D (moved to the left till superposition has been attained), then, owing to the retention of impressions on the retina, the distinction between the black and white lines will be exactly obliterated, and a tint of gray produced, as can be shown by a construction. In fig. 4 the first and last views *only* are given; but as the action is an unbroken one, we must remember that between them properly belong a great number of pictures, with a gradually increasing displacement. Taking this number, for example, as eleven, then, on completing the construction which is begun in fig. 5 so as to correspond with fig. 4, it will be seen that the result is a gray streak shading into white at its upper and lower boundaries, and that all the interior portions are composed either of resultants produced by adding five parts of black to six of white, or the reverse. And in general, if we set the number of views equal to some odd number greater than unity, we shall obtain for the interior portions $\frac{n-1}{2}$ parts of black, with $\frac{n+1}{2}$ of white, or the reverse; so that the greater the number of views used in the construction, or the more we approach to the real state of the case in nature, the more perfect will be the balance of black and white obtained. And this conclusion is justified by experiment; for if two black sec-

4.



5.



tors, inclosing between them a white sector of equal breadth, are painted on a white circular disc of card-board, and viewed in a mirror through an aperture cut in the same disc, when it is made to revolve, these sectors will be distinguishable until the observing aperture has been widened so that it is equal in breadth to *two* of the painted sectors, when only a band of gray will be seen, uniform in its interior portions, and shading into white at its two extremities, according to the indications of the construction. Furthermore, making the disc experiment afresh, as the observing aperture is gradually widened, it is easy to note the growing obscurity and lack of sharpness in which the sectors become involved, which may hereafter serve to interpret corresponding changes in the image produced by the electric discharge, or explain and give a meaning to their absence.

Instead of using only two lines, the same result can far more easily be attained by ruling paper with a large number of fine black lines, equidistant, and inclosing white spaces of their own breadth, as then the chances for observation are greatly multiplied. A construction made on the same plan, for a set containing a large number of lines of this character, will show that the same law again prevails, that the extremes shade into white, and that all the interior portions are of a uniform gray tint; hence, that when a superposition such as indicated in fig. 4 has been obtained, all the lines will, by the retention of impressions on the retina, be obliterated. Naturally, experiment with the disc gives the same result.

Accordingly, I again used the same set of lines (on paper) mentioned in Part First of this article, and illuminated them with the electric discharge now under consideration. With the mirror revolving 340 times in a second, using platinum points and a striking distance of two millimeters, the lines were still seen with an eye-piece, as bright and clear as though the mirror had been stationary, implying, as the apparatus was then arranged, a duration, for the first act, of less than three ten-millionths of a second, which interval would have been required for destructive superposition. Nothing more could be done with paper, and accordingly I covered a glass plate with lamp-black by smoking, and poured over it a few drops of alcohol, which, acting like a slight cement, enabled me to rule lines on it with a small dividing engine. After many trials and microscopic examinations, a plate was produced with lines black and white of equal breadth, and the spark being discharged behind them, they were brightly illuminated. Their image was thrown on the observing plate, and by using a sufficient magnifying power and counting, it was ascertained that the breadth of the image of a single line, black or white, was $\frac{1}{12}$ of a millimeter. Hence, the time required for their obliteration, with a velocity

of 340 per second, was ninety-four billionths of a second (·000000094); still, on experimenting, it was evident that the duration of the discharge was less than this quantity, as the lines were always plainly to be seen.

Duration of the first act of the discharge.

Before finally abandoning the attempt to determine the actual duration of the discharge, another effort was made; a second lamp-black plate was prepared, in which the breadth of the image of a line, black or white, on the observing plate was $\frac{1}{24}$ of a millimeter. These lines were viewed with the terrestrial eye-piece of a small telescope; it enlarged them ten diameters, and care was taken with all the adjustments so that a good clean image should be produced. Platinum wires $\frac{1}{86}$ of an inch in diameter were used with a striking distance of five millimeters. By gradually increasing the weight, it was proved successively that the duration was less than eighty, sixty-eight, fifty-nine, fifty-five billionths of a second; and finally, the lines after growing fainter and fainter, entirely disappeared, giving as the result a duration of forty-eight billionths of a second. In a large number of observations I could detect no discharge lasting during a smaller interval, though the apparatus was now fully capable of making evident much smaller periods of time.

When the striking distance was reduced to one millimeter, the duration was shorter; in the case of $\frac{5}{6}$ of the sparks, the duration was slightly greater than forty-one billionths of a second, the remaining $\frac{1}{6}$ being slightly less than this figure.

With a striking distance of three millimeters, the duration was between forty-one and forty-eight billionths; and when the striking distance was increased to ten millimeters, it was between forty-eight and fifty-five billionths of a second.

An effort was made to make a corresponding set of measurements with brass balls instead of platinum points; and it would seem probable that the duration of the discharge is somewhat increased by their use (or that many of those with shorter durations are suppressed). With brass balls not nearly so many discharges take place in a given time as with points; hence, the work becomes tedious and less certain. The evidence from twenty-six observations, gathered in not less than three hours, went to show that the duration with a striking distance of five millimeters was between forty-eight and fifty-five billionths of a second.

It has thus been shown that the duration of the first act of the electric discharge is in certain cases only forty billionths of a second, an interval of time just sufficient to enable a ray of light to travel over forty feet. This act, however, is only *practically* isolated; from a scientific point of view it is really the distance

A B, fig. 3, which has been measured; and as we are ignorant of the true curve, it might be objected that the real curve might just as well be supposed to be like that given with dotted line. There is, however, experimental evidence to show that this is not the case; for on this supposition, the blurring of the image would begin to be visbile far earlier, i. e., with lower velocities than has been observed. In point of fact, the image remains visibly as distinct as with a stationary mirror till a certain stage, when it begins to be affected, becomes regularly less distinct, and vanishes; between this stage and the final disappearance, there is included an interval of time which is barely accounted for by the gradual superposition of the white and black lines, as I assured myself by parallel experiments with revolving discs, provided with black and white sectors, and an observing aperture of varying size.

Hence it is seen that we have an excellent source of illumination, which has a practical duration of only forty billionths of a second (·00000004); and I am not without hope that it may hereafter be applied to the solution of a number of interesting scientific problems. I may finally add that with another ruled plate, I found it practicable to measure intervals as small as twenty-eight billionths of a second; and the mere act of increasing the focal length of the lens L would admit of the experimenter reaching a quantity as small as ten billionths—probably without much difficulty—though it would be necessary to pay more attention to the correction of the optical part of the apparatus, and the observations would naturally consume threefold as much time.

Duration of the first act, with a Leyden jar having a coating of 114·4 *square inches.*

With the improvements above described, no difficulty was experienced in making this determination, which, as shown in Part First of the present paper, had on a previous occasion defied all my efforts. Platinum points and a striking distance of two millimeters were employed in connection with the coarsest of the three lamp-black plates; but when the mirror made only 183 turns in a second, it was ascertained that the duration of this first act was ·000000175 of a second, or about four times as great as with the small jar and the same striking distance.

New York, June 29th, 1871.